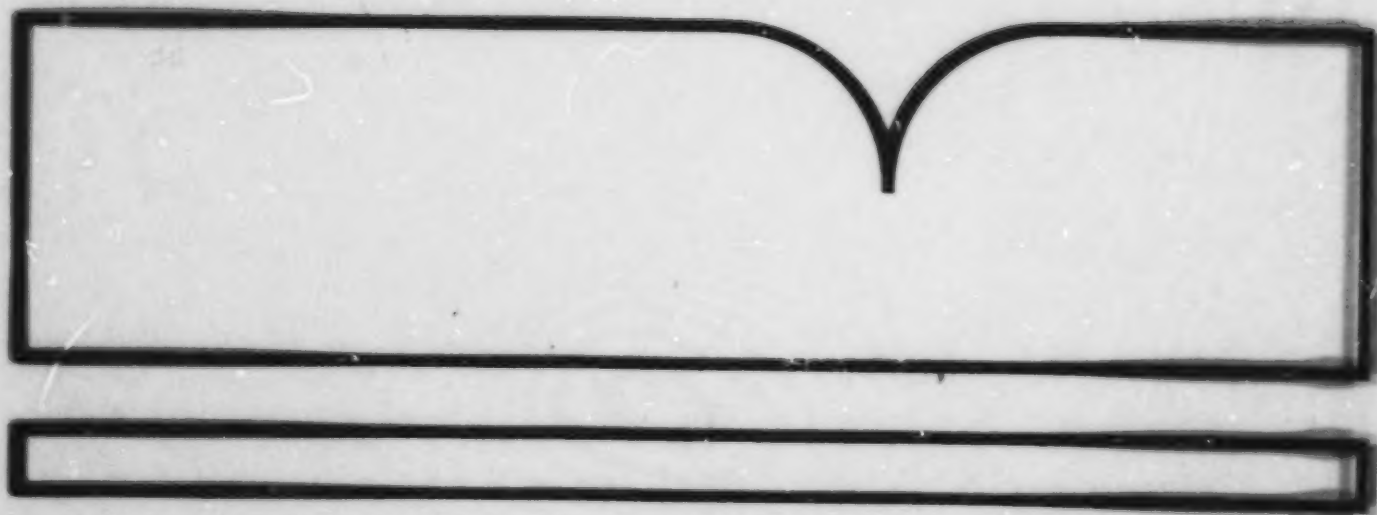


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Toxicity of Sediments from
Three Metal-Contaminated Areas

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TOXICITY OF SEDIMENTS FROM THREE METAL-CONTAMINATED AREAS

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Abstract — Sediments from Phillips Chain of Lakes (Wisconsin), Torch Lake (Michigan), and Little Grizzly Creek System (California) were tested for acute toxicity using the water flea, *Daphnia magna*, and the burrowing mayfly nymph, *Hexagenia limbata*. The organisms were tested simultaneously in a laboratory recirculating bioassay apparatus; *Daphnia* were tested during the first two (*Daphnia* I) and the last two (*Daphnia* II) days of 10-d *Hexagenia* tests.

Sediment from one of six sampling locations from the Phillips Chain of Lakes was toxic to *Daphnia* I, but not *Daphnia* II. None of these sediments was toxic to *Hexagenia*.

Contaminated sediments from Torch Lake and the Little Grizzly Creek System were highly toxic to *Daphnia* I and II, and *Hexagenia*.

In general, numbers of organisms, biomass, species diversity and dominant types of organisms correlated with metal content and acute laboratory toxicity.

Keywords — Sediment Toxicity tests benthic macroinvertebrates *Daphnia* *Hexagenia*
Phillips Chain of Lakes, WI Torch Lake, MI Little Grizzly Creek System, CA

INTRODUCTION

All fine sediments contain trace concentrations of heavy metals at levels that reflect the composition of soil and/or bedrock in the watershed. Cultural activities, however, sometimes result in sediment-metals concentrations many times higher than natural background and can disrupt benthic community composition and abundance [1,2]. The purpose of this study was to determine if acute toxicity would be caused by sediments from three metals-contaminated freshwater ecosystems and to correlate laboratory toxicity test results with bulk sediment chemistry, aqueous chemistry during bioassays, and characteristics of the benthic invertebrate communities.

The first site was near a metals-plating factory located in the City of Phillips,

Wisconsin, which discharged process wastewater to the city sewer system until November 1978. Samples taken in 1975 showed that sediment areas near the sewage treatment plant outfall in Elk Lake contained high concentrations of cadmium, chromium, copper, mercury, nickel, and zinc (T. R. Smith, personal communication). Maximum dry weight concentrations in mg/kg were Cd, 18.2; Cr, 19,053; Cu, 5557; Hg, 4.5; Ni, 5954; and Zn, 1350. Elevated concentrations of some of these metals were also found in the water of Elk Lake and downstream in Long Lake. In addition, elevated metal content was measured in the plankton and benthic macroinvertebrates of these lakes. The metals plating factory now operates its own treatment facility but discharges treated effluent to the same location

in Elk Lake as the municipal treatment plant (T.R. Smith, personal communication).

Torch Lake, the second site, is located on the Keweenaw Peninsula of Upper Michigan and has been contaminated with Cu mine tailings from the once-booming copper mining industry of that area. Wright et al. [3] estimated that 20% of the lake volume was filled with Cu tailings between 1946 and 1970. Copper concentrations of Torch Lake sediment were reported to range from 1310 to 3860 mg/kg [4].

Little Grizzly Creek, the third site, is located in Plumas County, California, on the western slope of the Sierra Nevada Mountains. It is a second-order stream and receives the drainage from the Walker Mine which operated during the first half of this century and was one of California's most productive copper mines [5]. Millions of tons of process tailings now are deposited adjacent to Dollie and Little Grizzly Creeks. Mine drainage as well as erosion from tailings now contaminate the streams. Copper concentrations of Little Grizzly Creek System sediments were reported to range from 14,050 mg/kg just downstream from the mine to 2636 mg/kg farther downstream [5].

MATERIALS AND METHODS

Sediment samples

Samples of surface sediments were obtained from six sites in Phillips Chain of Lakes, Wisconsin, one site in Torch Lake, Michigan, and ten sites in Dollie, Little Grizzly and Indian Creeks, California (Little Grizzly Creek System). In addition, sediment was collected from Soap Creek Pond No. 7, Oregon, for control or reference tests.

The Phillips sediment samples were collected by Ponar grab from Elk, Long and Wilson Lakes, Price County, Wisconsin, on May 25, 1982 (Figure 1). They were shipped by air in iced coolers and arrived at the USEPA's Corvallis (Oregon) Environmental Research Laboratory (CERL) two

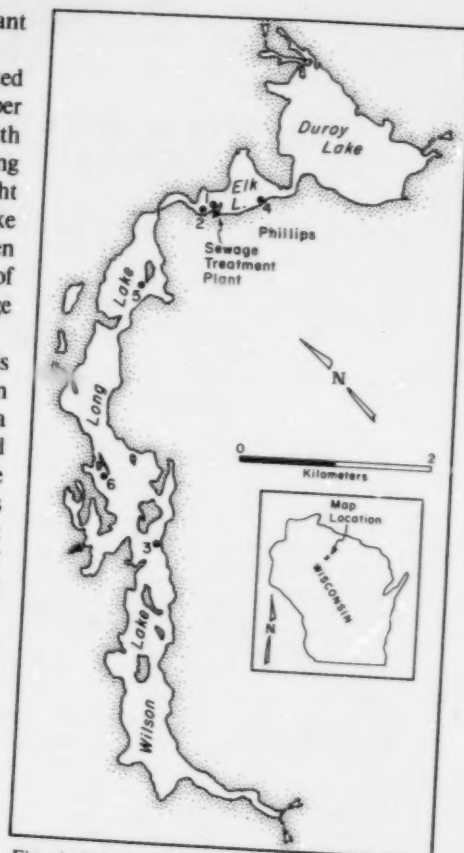


Fig. 1. Location of Phillips Chain of Lakes sampling sites.

days later. In addition, samples were taken for macroinvertebrate analysis by Ekman grab; organisms were separated from the sediment, preserved in ethanol, identified, and counted. All samples were collected at depths of approximately 2-3 m.

Species diversity (H') was calculated according to the Shannon-Weaver expression [6]. The number of species in the top 75% of the population was also calculated (R. C. Swartz, unpublished method).

The single sample of sediment from Torch Lake, Houghton County, Michigan (Figure 2) was collected at a depth of approximately 20 m by grab sampler on October 14, 1982, and refrigerated. The sediment was shipped to the CERL in an iced cooler



Fig. 2. Location of Torch Lake sampling site, station 4.

by air, arriving on November 10, 1982, within one day of shipment.

The Dollie, Little Grizzly, and Indian Creeks (Figure 3) sediment samples were obtained on October 2, 1982, by hand scooping surface sediment into sample jars which were then refrigerated. The samples were shipped in iced coolers to the CERL by surface freight on October 5 and 14 and arrived the following days.

Upon arrival at the CERL, all samples were immediately stored at 5°C until tested. Control sediment from Soap Creek Pond No. 7 was obtained by Ekman grab as necessary. This pond, located north of Corvallis in a semi-restricted rural area, has no known point or non-point sources of pollution.

Dilution water

The test water was obtained from a well located near the Willamette River at the Western Fish Toxicology Station, a CERL facility. This water is relatively soft, with low levels of dissolved constituents (Table 1).

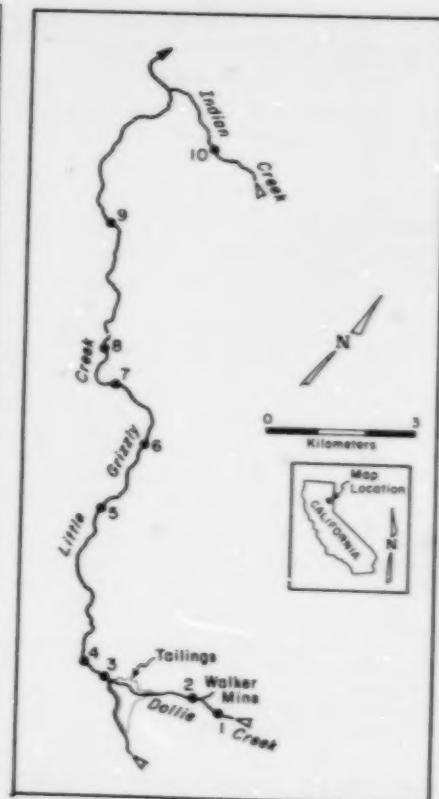


Fig. 3. Location of Little Grizzly Creek System sampling sites.

Test organisms

The test organisms were the water flea, *Daphnia magna*, and the burrowing mayfly nymph, *Hexagenia limbata*. *Daphnia* used were ≤ 24 h old, obtained from a stock culture maintained at the toxicology station. *Hexagenia* were collected in Wisconsin and shipped to CERL in iced containers. Further information on culturing, collection, feeding and maintenance of test organisms can be found in Malueg et al. [7].

The test apparatus

The toxicity tests were conducted in an Anderson-Prater type recirculating test apparatus consisting basically of a rectangular

Table 1. Chemistry of initial water for experiments^a

Parameter	mg/l	SD	Range
Ca	5.7	0.15	5.5 - 5.8
Mg	1.8	0.1	1.7 - 1.9
Na	5.1	0.06	5.0 - 5.1
K	0.62	0.06	0.56 - 0.67
Cl	4.1	0.81	3.4 - 5.0
SO ₄	1.0	0.35	0.7 - 1.4
Alkalinity (CaCO ₃)	26 ^b	1.6	24 - 27
Hardness (CaCO ₃)	22 ^b	0.6	21 - 22
Sp. Conductance	67 ^c	3.1	64 - 70
Al	< 0.08 ^d		
As	< 0.08		
Cd	< 0.005		
Cr	< 0.01		
Cu	< 0.01		
Fe	0.071	0.013	0.060 - 0.085
Mn	< 0.01		
Ni	< 0.04		
Pb	< 0.05		
Sr	0.028	0.002	0.027 - 0.030
V	< 0.01		
Zn	< 0.01		
NH ₃ - N	< 0.04		
NO ₂ + NO ₃ - N	0.26	0.05	0.22 - 0.31
TKN - N	< 0.14		
O - PO ₄ - P	0.038	0.006	0.033 - 0.044
Total PO ₄ - P	0.038	0.003	0.036 - 0.042

^aDetermination of initial water samples used in reported experiments, each with replicates.^bCalculated.^cSpecific conductance as $\mu\text{mhos/cm}$.^d< Values are detection limits.

glass chamber positioned over two 4-liter jars [7]. The sediment (5 cm deep) was placed in the bottom of the glass chamber and water (~ 7 cm deep) was continually circulated over the sediment from the two jars. After one day of system equilibration, five *Hexagenia* nymphs were placed in the sediment for 10 d while twenty *Daphnia* were placed in a submerged vessel located in the water of the chamber above the surface of the sediment. Two *Daphnia* tests were run, the first (DI) during the initial 48 h and the second (DII) during the last 48 h of the 10-d period. Three replicates were run for each sediment. A Chi-square analysis was used to test for differences between pooled control and test survival at the 0.05 level of significance using a multiple comparison procedure where the α level was divided by the number of non-independent comparisons to a common control [8].

Analytical procedures

Sediment grain size was determined according to USEPA methods [9]. Most metal concentrations in the water and sediment were determined by inductively coupled plasma-atomic emission spectrometer methods [10] following the acid extraction method for sediment of Sinex et al. [11]. Analysis of lead and cadmium following extraction was by atomic absorption spectroscopy using flame or carbon furnace techniques. Total carbon was determined according to Patterson [12]. Total inorganic carbon was determined by a modification of the calcimeter method of Allison and Moodie [13] and a modified direct injection technique of Suzuki et al. [14]. Total organic carbon was by difference. All other chemical determinations were by USEPA methods [15]. The precision of copper and chromium in water was $\pm 10 \mu\text{g/L}$ or 10%

of higher values. Recovery of spiked samples exceeded 90%. Reference soils SO-1 through 4 from the Canadian Certified Reference Materials Project were analyzed concurrently with the sediment samples to verify efficiency of digestion procedures and to determine recovery on a standardized sample. Recovery was within 20% of reported values. Sediments were analyzed in triplicate. Results for bulk constituents were within $\pm 10\%$. The test apparatus was sampled before and after DI and before and after DII.

RESULTS

Phillips Chain of Lakes

No mortality of *Daphnia* occurred with the control sediment in either 48-h test (DI and DII). The only significant mortality for test sediments occurred in Elk 1, the station nearest the outfall (Table 2).

Hexagenia mortality in control sediment was 6.7%. None of the test sediment mortalities was significantly different from this value (Table 3).

Bulk chemical analysis on Elk 1 sediment indicated the following levels of contaminants in mg/kg: Cd, 4.9; Cr, 980; Cu, 540; Ni, 350; and Zn, 570 (Table 4). None of these concentrations was exceeded in the other stations. Elk 2 was the next most contaminated site.

Analysis of the recirculating test water showed only total Cr and Cu were present in detectable amounts. Concentrations of Cr at the end of the first 48 h peaked at about 0.150 mg/l for Elk 2 and about 0.100 mg/l for Elk 1. Copper concentrations at the same time were about 0.060 and 0.050 mg/l, respectively. These concentrations slowly increased in the interval between the two *Daphnia* tests and peaked at the beginning of DII at about 0.225 mg/L Cr for Elk 2 and 0.200 mg/L Cr for Elk 1. Copper concentrations were about 0.110 and 0.100 mg/L, respectively. Concentrations of both

metals then decreased during the second 48-h test (DII).

Dissolved oxygen in the control chambers averaged 6.0 ± 1.2 mg/L; test chamber oxygen values averaged 7.1 ± 1.0 mg/L. Control water pH ranged from 6.7 to 7.1 and test water pH ranged from 6.4 to 7.3.

Torch Lake

Daphnia mortality was extremely high in both tests, ranging from 97% in DI to 100% in DII. Control mortality was very low—1.7% in both DI and DII (Table 2). Mortality of *Hexagenia* was 40%, significantly higher than for the control (6.7%) (Table 3).

Bulk sediment analysis indicated a concentration of Cu of 1800 mg/kg (Table 4). Total copper in the water increased from about 0.6 mg/L at the end of DI to about 1.2 mg/L at the beginning of DII and then decreased slightly during DII.

Dissolved oxygen in the control tests averaged 6.8 ± 0.8 mg/L. Mean dissolved oxygen in the test chambers was 6.0 ± 1.2 mg/L. Control pH ranged from 6.9 to 7.5 and test pH ranged from 7.3 to 7.8.

Little Grizzly Creek System

Daphnia mortality was 100% in both DI and DII in tests for all stations downstream from the mine. Mortality in the test sediment upstream from the mine, Station 1, was 0%, while that in Station 10 on Indian Creek, upstream from the confluence of Little Grizzly Creek, was 1.7%. No mortality was detected in either control test (Table 2).

Hexagenia mortality in the control was 6.7%. Mortalities for all mine-impacted stations were significantly greater than this value (Table 3). A more detailed view of *Hexagenia* response is illustrated in Figure 4 where the stations are ranked in toxicity gradients. Station 4 sediment was the most toxic, with 100% mortality within 72 h, followed by Stations 2 and 3, with high early test mortalities. All three of these stations were closest to the mine and tailings.

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Table 2. Comparative toxicity of test sediments to *Daphnia* in 48 h tests, at beginning and end of 10-d *Hexagenia* test

Sediments	Daphnia I		Daphnia II		Results of X ² Analysis	
	Survivors/ Total	% Mortality	Survivors/ Total	% Mortality	Daphnia I Test vs Control	Daphnia II Test vs Control
<i>Phillips Chain of Lakes</i>						
Elk 4	60/60	0.0	57/60	5.0	0*	0
Elk 1	50/60	16.7	56/60	6.7	+	0
Elk 2	60/60	0.0	58/60	3.3	0	0
Long 5	57/60	5.0	60/60	0.0	0	0
Long 6	59/60	1.7	60/60	0.0	0	0
Wilson 3	59/60	1.7	57/60	5.0	0	0
Control	60/60	0.0	60/60	0.0		
<i>Torch Lake</i>						
Torch 4	2/60	96.7	0/60	100.0	+	+
Control	59/60	1.7	59/60	1.7		
<i>Little Grizzly Creek System</i>						
Dollie 1	59/60	1.7	60/60	0.0	0	0
Grizzly 2	0/60	100.0	0/60	100.0	+	+
Grizzly 3	0/60	100.0	0/60	100.0	+	+
Grizzly 4	0/60	100.0	0/60	100.0	+	+
Grizzly 5	0/60	100.0	0/60	100.0	+	+
Grizzly 6	0/60	100.0	0/60	100.0	+	+
Grizzly 7	0/60	100.0	0/60	100.0	+	+
Grizzly 8	0/60	100.0	0/60	100.0	+	+
Grizzly 9	3/60	100.0	0/60	100.0	+	+
Indian 10	60/60	0.0	59/60	1.7	+	+
Control	60/60	0.0	60/60	0.0	0	0

* 0 = No significant difference ($\alpha = 0.05$).

+ = A significant difference.

Hexagenia larvae could be observed daily because they were unable to burrow into the sandy sediments, with the exception of the fine black organic material of Station 1. Survival in the two non-impacted test sediments at Stations 1 and 10 was not significantly different from that of the control.

The highest concentrations of sediment Cu were from samples closest to the mine, with lesser amounts at greater distances (Table 4). For instance, bulk sediment Cu content was over 2700 mg/kg at Station 2 but only 550 mg/kg at Station 9. The two non-impacted stations, #1 above the mine and #10 above the confluence of the impacted creek, had concentrations of 60 and 16 mg/kg, respectively. A gradient of Cu contamination thus existed. Other chemical parameters do not show this trend of decreasing values away from the mine.

Copper was the only toxic metal present in test water in detectable quantities. Total

Cu in the test water was especially high for Station 4 (Figure 5). The Cu concentrations at this station during DI ranged from over 0.7 mg/L at the beginning to about 3.5 mg/L at the end. The DII values were lower and ranged from almost 2.5 to about 2.2 mg/L, respectively.

Control dissolved oxygen average 7.5 ± 0.5 mg/L; test values averaged 8.6 ± 0.3 mg/L. Control pH ranged from 7.1 to 7.5 while that in the test chambers ranged from 7.2 to 8.0.

FIELD MACROINVERTEBRATE DATA

Phillips Chain of Lakes

Station 1, located in the area of greatest contamination and the only station with significant laboratory *Daphnia* mortality, was characterized by few taxa, the least biomass and lowest species diversity in the Phillips

Table 3. Comparative toxicity of test sediments to *Hexagenia*, 10-d test

Table 3. Comparative toxicity of test sediments to <i>Hexagenia</i> , 10-d test			
Sediments	Survivors/Total	% Mortality	Results of χ^2 Analysis
			Test vs Control
<i>Phillips Chain of Lakes</i>			
Elk 4	14/15		
Elk 1	14/15	6.7	
Elk 2	13/15	6.7	0*
Long 5	13/15	13.3	0
Long 6	14/15	13.3	0
Wilson 3	13/15	6.7	0
Control	14/15	13.3	0
		6.7	0
<i>Torch Lake</i>			
Torch 4	9/15		
Control	14/15	40.0	
		6.7	+ ^b
<i>Little Grizzly Creek System</i>			
Dollie 1	13/15		
Grizzly 2	0/15	13.3	
Grizzly 3	1/15	100.0	0
Grizzly 4	0/15	93.3	+
Grizzly 5	1/15	100.0	+
Grizzly 6	0/15	93.3	+
Grizzly 7	0/15	100.0	+
Grizzly 8	0/15	100.0	+
Grizzly 9	0/15	100.0	+
Indian 10	12/15	100.0	+
Control	14/15	20.0	+
		6.7	0

* 0 = No significant difference ($\alpha = 0.05$).
+ = A significant difference.

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Chain of Lakes (Table 5). There were only seven taxa and a biomass of 2.24 g/m² dry weight. Species diversity, as expressed by H' and by the number of species in the top 75% of the total population, was 0.47 and 1.38, respectively. In contrast, Station 3 in Wilson Lake, farthest from the contaminated area, was characterized by 12 taxa, a biomass of 12.03 g/m² dry weight, an H' diversity of 0.89 and 3.98 species in the top 75% of the population.

The phantom midge, *Chaoborus punctipennis*, comprised over 62% of the population at Station 1 (Table 5). Oligochaetes made up only about 3% of the population at this station in contrast to about 70% and 60% immediately upstream and downstream at Stations 4 and 2. The percentage of chironomids at Station 1, 20.7%, was also lower than the percentage at all of the other

stations where it ranged from 28 to 65% (Table 6).

Torch Lake

Torch Lake, sampled for benthic macroinvertebrates in 1979¹, was characterized by low diversity and reduced populations. The predominant organisms were oligochaetes and chironomids (Table 7). Sediment for our toxicity test was collected from Station 4 which had only 14 dipterans, none of which were identified further than Order, per m² (Table 8). Yanko [16] collected only the chironomid *Pentaneura* from this site. Data from other sampling stations are included for comparison purposes.

Torch Lake flows into the nearby Keweenaw Waterway. The southern portion of the Waterway receives relatively minor copper contamination and therefore

¹Michigan Department of Natural Resources

Table 4. Bulk sediment analysis mg/kg dry weight basis

	Cd	Cr	Cu	Hg	Ni	Pb	Sr	V	Zn
<i>Phillips Chain of Lakes</i>									
Elk 4	3.2	430	180	0.8	140	120	37	70	230
Elk 1	4.9	980	540	9.4	350	160	40	73	570
Elk 2	4.0	650	320	3.2	210	110	42	62	410
Long 5	3.0	300	96	0.8	100	58	35	74	170
Long 6	2.7	140	50	0.3	60	59	31	57	140
Wilson 3	2.5	57	30	0.01	19	46	34	54	130
<i>Torch Lake</i>									
Torch 4	2.5	180	1800	0.29	150	110	70	250	310
<i>Little Grizzly Creek System</i>									
Dottie 1	1.3	84	60	1.3	24	31	83	99	160
Grizzly 2	0.8	40	2700	0.8	30	20	18	47	99
Grizzly 3	1.2	34	2000	1.2	22	69	40	32	120
Grizzly 4	1.2	40	2200	1.2	26	47	52	54	220
Grizzly 5	1.0	93	750	1.0	30	24	41	75	100
Grizzly 6	1.1	94	1000	1.1	39	27	46	72	100
Grizzly 7	1.3	94	1100	1.2	51	26	50	73	120
Grizzly 8	1.1	150	690	3.5	63	20	52	76	430
Grizzly 9	1.7	150	550	1.7	60	20	40	68	950
Indian 10	0.3	28	16	0.3	<7	5	29	57	29
Control	2.5	300	200	<0.02	120	21	66	390	150

represents somewhat of a control area with which to compare Torch Lake benthic macroinvertebrates. Recent sampling showed that the mayfly, *Hexagenia*, was the numerically dominant taxon in the south Waterway with chironomids comprising less than 25% of the fauna [17].

LITTLE GRIZZLY CREEK SYSTEM

The Little Grizzly Creek System was sampled for benthic macroinvertebrates in 1975 and in 1976 at 16 sites [5]. Five of these correspond to sediment sample sites 1, 2, 3,

4, and 9 in the present study (Table 9). No organisms were found at Station 2 below the mine; however, farther downstream, populations increased from an average of 350

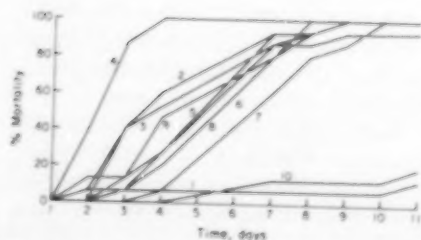


Fig. 4. Little Grizzly Creek *Hexagenia* toxicity test. Numbers indicate stations.

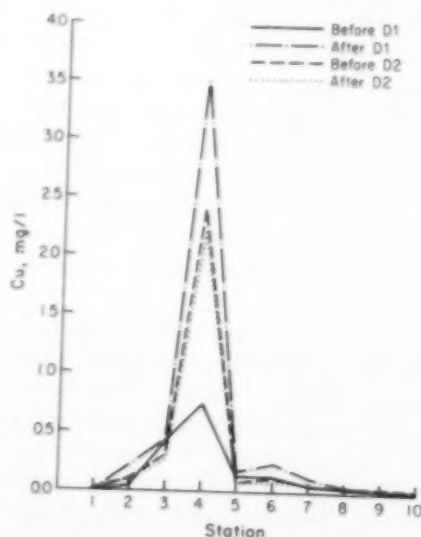


Fig. 5. Copper concentration in test waters exposed to sediment from Little Grizzly Creek.

Table 5. Phillips Chain of Lakes macroinvertebrate analysis

Stations	Community Structure				Diversity ^a		Composition	
	No. Animals/ m ²	No. Taxa	Biomass g/m ² dry wt	H'	Species		Numerically Dominant Taxa	%
					top	75%		
Elk 4	1607	7	9.83	0.61	2.38		<i>Limnodrilus hoffmeisteri</i>	22.3
Elk 1	832	7	2.24	0.47	1.38		<i>Chaoborus punctipennis</i>	62.1
Elk 2	1406	11	19.92	0.80	3.46		<i>Limnodrilus hoffmeisteri</i>	28.6
Long 5	430	9	3.64	0.87	4.50		Oligochaeta	23.3
							<i>Chaoborus punctipennis</i>	16.7
							<i>Procladius</i>	16.7
Long 6	617	11	5.22	0.77	4.00		<i>Chironomus plumosus</i>	16.7
Wilson 3	1191	12	12.03	0.89	3.98		<i>Procladius</i>	46.5
							<i>Procladius</i>	20.4
							<i>Chaoborus punctipennis</i>	16.9
							<i>Limnodrilus hoffmeisteri</i>	13.2

^aDoes not include unidentified forms.

organisms per m² at Station 3 to 1826/m² at Station 9. There were 64 taxa at Station 1 on Dollie Creek above the mine and 18 to 36 taxa at Stations 3 to 9. Dipterans were dominant at these latter sites. In 1976, no Ephemeropterans were collected at Stations 3 and 4, but they averaged 15% of the population downstream at Station 9 (Table 10). Mean numbers of Trichopterans increased from 1.5% at Station 3 to 3.3% at Station 9. Plecopterans were collected only at Stations 3 and 4, averaging 3.5 and 11.3% of the population, respectively. Biomass showed a similar pattern of increasing values downstream from the mine, as did population numbers. Average biomass values for 1975-1976 ranged from 647 mg/m² dry weight at Station 3 to 3910 mg/m² at Station 9 [5].

DISCUSSION

The described laboratory tests were useful in determining the toxicity of sediment samples. The two organisms, *Daphnia* and *Hexagenia*, were appropriate test species, *Daphnia* being the most sensitive. Deaths for both organisms in these tests ranged from not significantly different from the control to total mortality. Survival of both species in the control sediment was excellent.

Two of our study sites, Torch Lake and Grizzly Creek, were contaminated with Cu mine tailings. In this regard, they were similar to sites studied by Malueg et al. in the Keweenaw Waterway, Michigan [17]. That study demonstrated higher *Daphnia* mortalities and more instances of significant differences between control and test mortality in the DII tests than in the DI tests. In this study, mortality was extremely high in both DI and DII at all contaminated sites.

Another type of response also was recorded in the Elk Station 1 test. Here we had significant mortality in DI but not DII. This reversal can possibly be explained, along with the lack of response from the other contaminated Elk Lake sites in general, by the relatively high organic carbon levels that may have complexed the metals. Organic carbon levels (%) for sediments tested were: Elk 4—14.9, Elk 1—14.2, Elk 2—15.3, Long 5—18.6, Long 6—25.6, Wilson 3—27.4, Torch 1—2.2, Dollie 1—11.1, Grizzly 2—1.0, Grizzly 3—0.8, Grizzly 4—1.0, Grizzly 5—0.9, Grizzly 6—0.6, Grizzly 7—1.0, Grizzly 8—0.8, Grizzly 9—1.4, Indian 10—0.6; control—3.7.

Our reported metals concentrations in the Phillips Chain of Lakes samples (Table 4) are considerably lower than the maximum observed by personnel from the

Table 6. Phillips Chain of Lakes biological field data, percent benthic macroinvertebrates

Taxa	Elk 4	Elk 1	Elk 2	Long 5	Long 6	Wilson 3
Amphipoda					2.3	1.2
Ephemeroptera			4.1		4.7	
Chaoboridae		72.4	10.3	16.7	16.3	20.5
Chironomidae	30.6	20.7	27.8	46.7	65.1	45.8
Ceratopogonidae		3.4		10.0		2.4
Heleidae				3.3		1.2
Megaloptera					4.7	
Isopoda					2.3	
Pelecypoda						6.0
Oligochaeta	69.4	3.4	57.7	23.3	4.7	4.8
						18.1

Table 7. Torch Lake biological field data 1979^a

Community Structure						
Stations	No./m ²	No. Taxa	Diversity		Composition	
			H'	Species top 75%	Numerically Dominant Taxa	%
Torch 1	91	3	0.37	1.42	<i>Chironomus</i>	66.7
Torch 2	73	4	0.47	1.67	<i>Chironomus</i>	58.3
Torch 3	172	4	0.52	2.00	<i>Chironomus</i>	50.0
Torch 4	14	1	0.0	100.00	Unidentified Diptera	100.0
Torch 5	230	2	0.10	0.80	Oligochaeta	93.7

^aFrom Michigan Department of Natural Resources.Table 8. Torch Lake biological field data, 1979, percent benthic macroinvertebrates^a

Stations	Oligochaeta	Chironomidae	Trichoptera	Unidentified Diptera
Torch 1	20.0	80.0		
Torch 2	25.0	66.7	8.3	
Torch 3	16.7	83.3		
Torch 4				
Torch 5	93.7	6.3		100.0

^aFrom Michigan Department of Natural Resources.

Table 9. Little Grizzly Creek System biological field data 1975-1976

Macroinvertebrate Community Structure					Composition ^c	
Station	Taxa		Biomass ^d		%	Numerically Dominant Taxa
	Mean No./m ^{2a}	No. ^b	Mean No. Spp./m ^{2c}	Mean mg dry wt/m ²		
Dollie 1	—	64	—	—	—	—
Little Grizzly 2	0	0	0	0	0	0
Little Grizzly 3	350	33	—	647	0	Diptera
Little Grizzly 4	363	18	1.4	1370	0	Diptera
Little Grizzly 9	1826	36	5.4	3910	15	Diptera

— = No data.

^aSheehan [5] Table 26.^bSheehan [5] Tables 29, 31, 32, and Appendix Table 1.^cSheehan [5] without chironomids, Table 33.^dSheehan [5] Table 27.^eSheehan [5] estimated from Figure 22, 1976 only.

Table 10. Little Grizzly Creek biological field data, percent benthic macroinvertebrates, 1976^a

Station	Diptera	Trichoptera	Plecoptera	Ephemeroptera	Other
Little Grizzly 3	69.7	1.5	3.5	1.7	23.7
Little Grizzly 4	86.3	0.7	11.3	0.0	1.7
Little Grizzly 9	79.3	3.3	0.0	15.0	2.3

^aSheehan [5] estimated from Figure 22.

Wisconsin Department of Natural Resources (WDNR) in their 1975 tests (T. R. Smith, personal communication). They recorded maximum values of 19,053 mg/kg Cr and 5557 mg/kg Cu from a surface to 5-cm section of a sediment core taken at Elk Station 1. They found decreasing values of 557 mg/kg Cr and 756 mg/kg Cu at a core depth of 15 to 23 cm.

In March 1982, an additional core was taken and analyzed by a WDNR contractor. Concentration of Cr and Cu ranged, respectively, from a maximum of 9,239 and 3,695 mg/kg in the 0 to 5 cm section, to 295 and 444 mg/kg in the 10 to 15 cm section, and to 52 to 48 mg/kg in the 25 to 30 cm section.

Our test sediment, collected two months later by grab sampler, probably integrated these 0 to 15 cm layers. Here, reported values of 980 mg/kg Cr and 540 mg/kg Cu are surprisingly similar to the previous values considering the differences in personnel, sampling time, collecting and analytical procedures, and the known heterogeneity of lake sediment.

Our "upstream" sediment sample taken at Elk 4, well above the effluent discharge, still indicates elevated metals concentration. Water circulation patterns probably result in transport of materials to this location throughout much of the year. Metal concentrations in Duroy Lake, upstream from Elk Lake, show baseline sediment levels of 33 mg/kg Cr, 22 mg/kg Cu, and 21 mg/kg Ni (T. R. Smith, personal communication). These values are very similar to those of other uncontaminated northern Wisconsin Lakes [18].

The complex effluent from the Phillips, Wisconsin, sewage treatment plant made up of both domestic sewage and treated metal

plating plant wastes containing Cu, Cr and Ni, has been subjected to several biological tests [19]. A 30% effluent concentration had significant adverse effects on the survival and growth of fathead minnows. There were noticeable increases in the gill purge rate and amplitude of the ventilatory signs of the bluegill sunfish. The effluent also inhibited the activity of urease and acetylcholinesterase in laboratory enzyme tests.

The very low levels of oligochaetes at Station 1 in Elk Lake (Table 6) suggest a possible relationship with the high levels of contaminating metals at this location. Brinkhurst and Jamieson [20] suggest that an absence or marked reduction of worms may indicate the presence of heavy metals. Brinkhurst and Cook [21] also suggest that oligochaetes are less tolerant of heavy metals than arthropods. In contrast, based on their own and other recent studies, Chapman et al. [22] suggest, that oligochaetes are among the benthic macroinvertebrates most tolerant to heavy metals. For instance, Wentsel et al. [2] found the oligochaete *Limnodrilus* to be abundant in the metal-impacted areas of Palestine Lake, Indiana. Chapman et al. [22] suggest, however, that studies by Whitley [23] and Brković-Popović and Popović [24] indicate that tubificid oligochaetes are more sensitive to Cu, Cd, and Hg in solution than to Zn, Cr, Ni, and Pb. Aston [25] reviewed tubificids and water quality and concluded that Cu was implicated in the reduction of tubificid populations. The high levels of Cu in the sediments at Station 1 of Elk Lake, therefore, may have had an adverse effect upon the oligochaete population.

Similar low levels of oligochaetes were also found at Station 6 in Long Lake downstream, where the metal content was lower. The sediments at this station, however, were characterized by fewer fines, with only about 34% of the material capable of passing through a 230-mesh sieve. Elk Lake Station 1 sediments were finer, with 65% passing through the sieve. Perhaps the oligochaetes at Station 6 responded more to the sediment texture and less to metal content than did the worms of Station 1.

Sheehan [5] observed in 1976 that the most copper-sensitive species in Little Grizzly Creek, ephemeropterans and plecopterans, were rare or absent from several locations downstream from the mine. These organisms were still absent from Station 4 in our study, indicating the persistent influence of the contaminated mine tailings.

Winner et al. [26] suggested that, in lotic ecosystems contaminated with heavy metals, midges dominate heavily polluted habitats; midges and caddisflies dominate moderately polluted habitats; and caddisflies and mayflies dominate minimally polluted or unpolluted habitats. In 1976, Little Grizzly Creek Stations 3, 4, and 9 were dominated by dipterans. Increased numbers of Trichoptera and Ephemeroptera at Station 9 during the present study indicates improved environmental conditions by Winner et al.'s guidelines. However, they cautioned that multiple samples must be collected throughout the seasons in order to adequately characterize community structure.

CONCLUSIONS

1. *Daphnia* and *Hexagenia*, when used together in the recirculating apparatus, were useful sensitive laboratory bioassay organisms for conducting acute metal toxicity sediment tests, with *Daphnia* being the most sensitive.
2. Sediment from one of six sampling locations from the Phillips Chain of Lakes

was toxic to *Daphnia* I, but not *Daphnia* II. None of these sediments was toxic to *Hexagenia*.

3. Contaminated sediments from Torch Lake and the Little Grizzly Creek System were highly toxic to both *Daphnia* and *Hexagenia*. Results from *Daphnia* I were similar to those from *Daphnia* II.
4. Elevated metal levels were present in sediment and bioassay test water where significant organism mortality occurred.
5. In general, numbers of organisms, biomass, species diversity, and dominant types of organisms correlated with metal content and acute laboratory toxicity.

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